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SOME YAWING TESTS OF A 1/30-SCALE MODEL OF THE HULL OF THE XPB2M-1 FLYING BOAT

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NACA

WASHINGTON

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ADVANCE RESTRICTED REPORT

SOME YAWING TESTS OF A 1/30-SCALE MODEL OF THE HULL OF THE XPB2M-1 FLYING BOAT

By F. W. S. Locke, Jr.

SUMMARY

The results obtained from yawing tests of a 1/30-scale model of the complete hull of the XPB2M-1 (Stevens Model No. 404) are shown to be in substantial agreement with preliminary full-scale flight tests on the flying boat. The model tests cover the entire range of speeds up to get-away, on the basis of the designed gross weight of the flying boat (140,000 lb).

Reports of preliminary flight tests of the XPB2M-1 flying boat indicated that there was a definite tendency toward directional instability in the vicinity of the hump. The model tests show that the hull is unstable at speeds up to and just past the hump. It was found that within the range $C_V = 2.0-2.5$ the curves of yawing moment are discontinuous at small yaw angles, and this has been associated with the difficulty found in the preliminary flight tests.*

INTRODUCTION

It has not been necessary, in the past, to give much attention to the directional stability characteristics of flying-boat hulls. Gott, in reference 1, suggested that directional instability was to be met with, only occasionally. Recently, the reverse has apparently become true. At least three modern flying boats have exhibited varying degrees of directional instability on the water.

*Since the tests herein reported were completed, small alterations to the hull, based upon model test findings, are reported to have substantially improved the directional stability characteristics.

Although the preliminary flight tests of the XPB2M-1 had shown directional instability primarily in the region of the hump, Gott's experience had shown instability at high speed. It was thought worth while, therefore, to make an investigation which would cover the entire range of speeds from zero to get-away. This investigation had two objectives:

1. To find curves of yawing moments against yaw, and to attempt a correlation of their shapes with the reported full-size behavior

2. To provide a background for future work

This investigation, conducted at the Stevens Institute of Technology, was sponsored by, and conducted with financial assistance from, the National Advisory Committee for Aeronautics.

DESCRIPTION OF MODEL

The model was built for The Glenn L. Martin Company, to their Drawing No. R240078, and was used by them for several investigations. It was used for the present investigation, in preference to other models, because it was a full model of the hull, complete with top and tail cone. The body plans are given in figure 1.

The center of gravity was located in the specified longitudinal and vertical positions, and on the centerline plane. The model was allowed to pivot freely about both the transverse and vertical axes, except in certain tests at high speeds, during which the trim angle was locked.

Particulars of the model and of the full-size flying boat are listed on page 7.

APPARATUS AND PROCEDURE

The model was mounted on bearings in a yoke. The bearings allowed pitching freedom and the yoke could be adjusted to produce fixed heel angles. The yoke was attached to a staff which allowed freedom in yaw and heave.

The angular motion of the staff was restrained by a calibrated spring, thus allowing determination of the yawing moment. A dashpot was provided for damping in yaw, which some preliminary experience had shown to be desirable. A sketch of the apparatus is shown in figure 2 and a photograph in figure 3.

The calibrated spring mentioned previously constituted the yawing moment dynamometer. The spring was relatively weak, and provision was made for changing its stiffness. The magnitude and direction of the yawing moment, at the running yaw angle, was determined by noting the difference between the angles of yaw when stationary and in motion. All moments and angles are referred to the wind axis (i.e., to the horizontal plane).

Up to about 12.5 feet per second (half get-away), the model was tested free to trim according to the schedule of loads previously used for a series of resistance tests on the same model, reported in reference 2. At higher speeds the model was tested at fixed trims, for which the loads were calculated from the aerodynamic characteristics of the flying boat. At each speed, sufficient tests were made to define the shape of the curve of yawing moment against yaw angle, especially in the region of small yaw angles. When free to trim, the trim and heave were recorded. All the tests were run at zero heel angle.

RESULTS

The following nondimensional coefficients are used:

Load coefficient,	$C_\Delta = \Delta/wb^3$
Speed coefficient	$C_V = V/\sqrt{gb}$
Trimming moment coefficient	$C_M = M/wb^4$
Yawing moment coefficient	$C_{M_\psi} = M_\psi/wb^4$
Heave coefficient	$C_h = h/b$

where

Δ load on water, pounds

w specific weight of water, pounds per cubic foot (62.3 for Stevens)

b beam at main step, feet

V speed, feet per second

g acceleration of gravity, 32.2 feet per second^2

M trimming moment, pound foot

M_ψ yawing moment, pound foot

h heave at center of gravity (height above position at rest and zero trim angle), feet

Moment data are referred to the center of gravity. Water trimming moments which tend to raise the bow are considered positive. Water yawing moments which tend to rotate the bow toward the right (starboard) are considered positive. Yaw angles to right of the course are considered positive.

Trim (τ) is the angle between the base line of the hull and the horizontal.

Yaw (ψ) is the angle between the center line of the hull and the course, measured in a plane parallel to the still-water surface.

DISCUSSION

The large chart in figure 18 is considered an important presentation of the results; it provides a comprehensive view of all of the directional stability characteristics under the given set of particulars. Each enclosed rectangle (or special shape where necessary) shows the curve of yawing moment against yaw angle for the speed and trim angle indicated by its center. Study shows that, in general, there are four types of curves. Taking the slope of the moment curve at zero yaw angle as a measure of the stability of the flying boat in yaw, the four types may be defined as follows:

Type	$dC_{M_\psi}/d\psi$
Positive stability	Negative
Neutral	Very small positive or zero
Negative stability	Positive
"Hooking" instability	Curve discontinuous at small angles

It will be seen that the hull is directionally unstable up to about half the get-away speed, except for a very small region. This small region of positive stability is enclosed by a contour line. The cases of "hooking" instability occur within a small region, which is also enclosed by a contour line. It will be noted that the region of instability starts at zero speed and extends almost up to the hump. At speeds above the hump, the hull is stable at high trim angles, where the afterbody is normally wetted; and neutrally stable at low trim angles, where the afterbody is normally clear. It would be expected that, once this hull has passed the hump, no trouble from directional instability would be encountered.

The report on preliminary flight tests of the actual XPB2M-1 flying boat bears out these indications of the model tests, at least in part. It states that, at speeds below the hump, "constant attention must be given to keep the flying boat headed very close to the course, and unbalanced power must be applied rapidly to check any deviation from the course. If corrective moment is not applied rapidly to check the first sign of yawing, the boat may become unmanageable. Cross-wind taxying may be very nearly impossible, even with maximum unbalanced power." As no remarks are made concerning directional stability past the hump, it is assumed that no trouble was experienced.

Some of the model test results are shown in detail in figures 4 to 17. The maximum available moments due to full rudder deflection, with balanced power, are marked on these charts. It will be seen that at low speeds the rudders are not nearly powerful enough to overcome the hydrodynamic yawing moments for anything more than a very small yaw. On the other hand, at high speeds, the available rudder moments are more than sufficient to control any deviation from the course. It appears, therefore, that any further work on directional stability may well be concentrated on the low- and hump-speed regions, and that, in these regions, no help should be expected from the aerodynamic controls. A satisfactory hull should presumably have neutral stability at all speeds.

Visual observations made during the tests indicated that the hooking instability in the vicinity of the hump was caused mainly by water which passed over the afterbody sides in the vicinity of the stern post and wetted the tail cone. Although sometimes noticeable under other conditions, this was especially noticeable where hooking instability occurred. In one or two of the tests with large yaw angles, at speeds in the vicinity of the hump, water washed right over the tail far enough forward to leave the rear gun turret out of water, and would probably have damaged the tail surfaces on the actual flying boat.

Gott (reference 1) used lighter loadings than the tests herein reported, and he used only relatively larger yaw angles. He found comparatively large unstable yawing moments at high speeds under these conditions. The present tests indicate that probably the same thing would have been found had they been carried to higher yaw angles. High yaw angles were not considered to be particularly important at high speeds for the flying boat under investigation because of the large available rudder moments. Gott found that, in general, increasing the trim angle improved the directional stability characteristics at high speeds, which agrees with the findings in the present tests.

CONCLUSIONS

1. The type of instability which gives most trouble in the full-size flying boat shows up as discontinuous moment curves in the model experiments - referred to as "hooking."

2. Water clinging to the afterbody sides and tail cone seems to be the cause of the discontinuous moment curves, and this is the region in which further work is likely to pay (in fact, already has paid) dividends.

3. In the region from just beyond the hump to get-away, the hull is either directionally stable or the available aerodynamic moments are sufficient for control.

Stevens Institute of Technology,
Hoboken, N. J., December 9, 1942.

REFERENCES

1. Gott, J. P.: Note on the Directional Stability of Seaplanes on the Water. R.& M. No. 1776, British A.R.C., 1937.

2. Davidson, Kenneth S. M., and Locke, F. W. S., Jr.: Some Systematic Model Experiments on the Porpoising Characteristics of Flying-Boat Hulls. NACA A.R.R., June 1943.

PARTICULARS AND SPECIFICATIONS	Full Size	Model
Navy Designation	XPB2M-1	
Martin Model No.	170	
Martin Drawing No.	R240078	
Stevens Model No.		404-1
Scale	1	1/30
Dimensions		
Beam at main step, inches	162	5.40
Angle between forebody keel and base line, degrees	2.0	*2.0
Angle between afterbody keel and base line, degrees	5.0	5.0
Height of main step at keel, inches	8.1	0.27
Center of gravity forward of main step (26.58 percent M.A.C.), inches	70.0	2.33
Center of gravity above base line, inches	146.7	4.89
Gross weight, Δ, pounds	140,000	5.19
Wing span, b, feet	200	6.67
Wing area, S, square feet	3683	4.092
Mean aerodynamic chord (M.A.C.), inches	249	8.30
Horizontal tail area, square feet	508	0.565
Vertical tail area, square feet	350	0.389
Distance, center of gravity to 35 percent M.A.C. horizontal tail (tail length), feet	63.6	2.12
Thrust line, above base line at main step, inches	230.3	7.68
Thrust line, inclined upward to base line, degrees	5.5	5.5

*All trim angles referred to base line.

Aerodynamic Characteristics

C_L at $\tau = 5^o$ (relative to base line)(flaps 30°)	1.585	1.585
L at $\tau = 5^o$	$6.95\ v^2$	$7.72 \times 10^{-3}\ v^2$
$dC_L/d\tau$	0.1045	0.1045
$dL/d\tau$, pounds per degree	$0.458\ v^2$	$0.509 \times 10^{-3}\ v^2$
$dC_{M_{CG}}/d\tau$ (av.)	-0.0150	-0.0150
$dM_{CG}/d\tau$, pound-foot per degree (av.)	$1.365\ v^2$	$5.05 \times 10^{-5}\ v^2$
$dC_{N_{CG}}/d\psi$ (av.)	-0.0006	-0.0006
$dN_{CG}/d\psi$ (av.)	$0.546\ v^2$	$2.02 \times 10^{-5}\ v^2$
$C_{N_{CG_{max}}}$ (max. rudder force)	0.0148	0.0148
Get-away speed, feet per second	130	23.74
Get-away C_L	1.890	1.890
Get-away τ, degrees	8.8	8.8

Ratios	$\frac{\text{Full-Size}}{\text{Model}}$
$\lambda^{1/2}$	5.477
λ	3.0×10
λ^2	9.0×10^2
λ^3	27.0×10^3
λ^4	81.0×10^4

(Station numbers are distances aft of fore point in inches for the full size.)

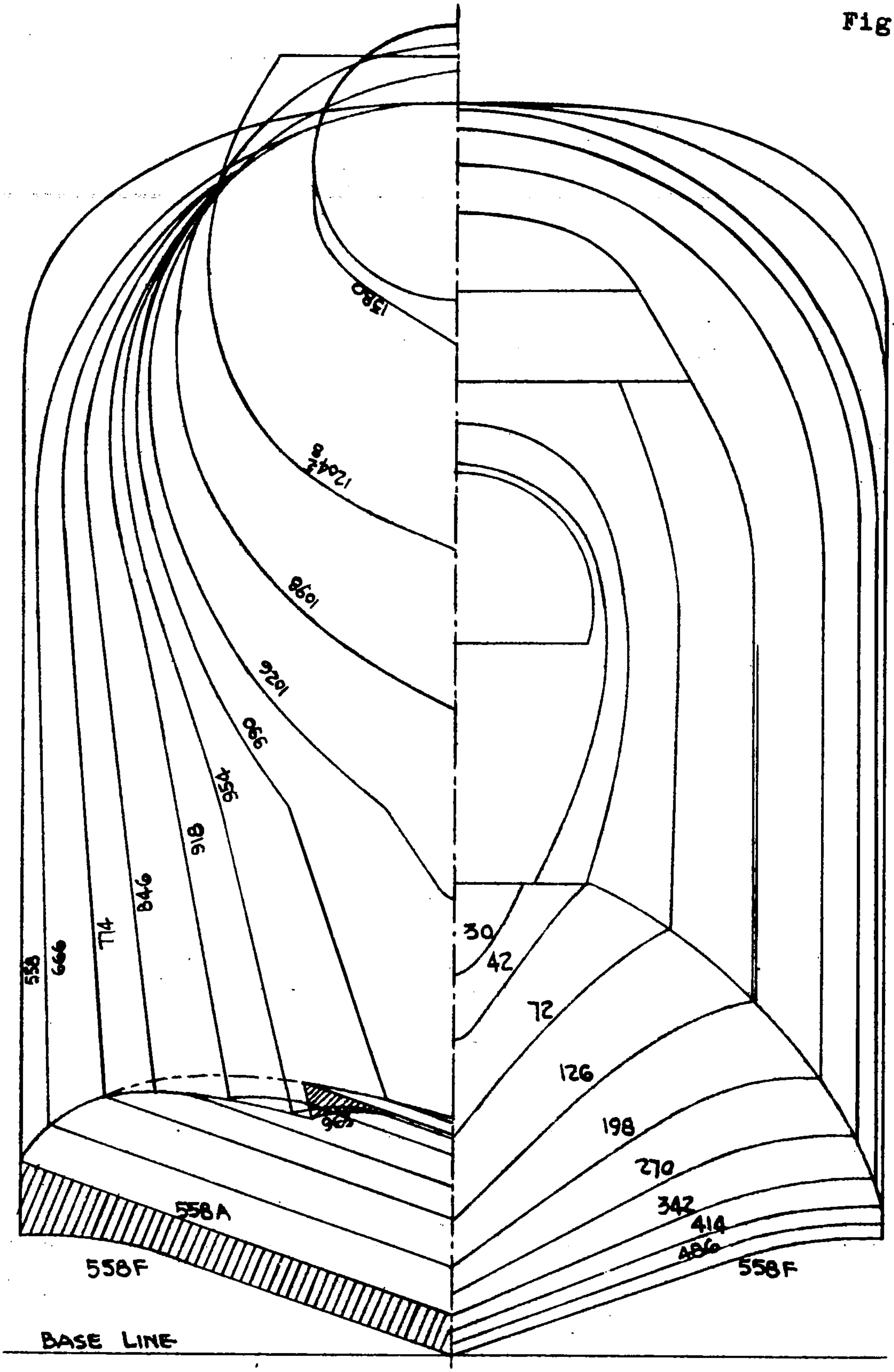

Figure 1.- Body plan of model XPB2M-1.

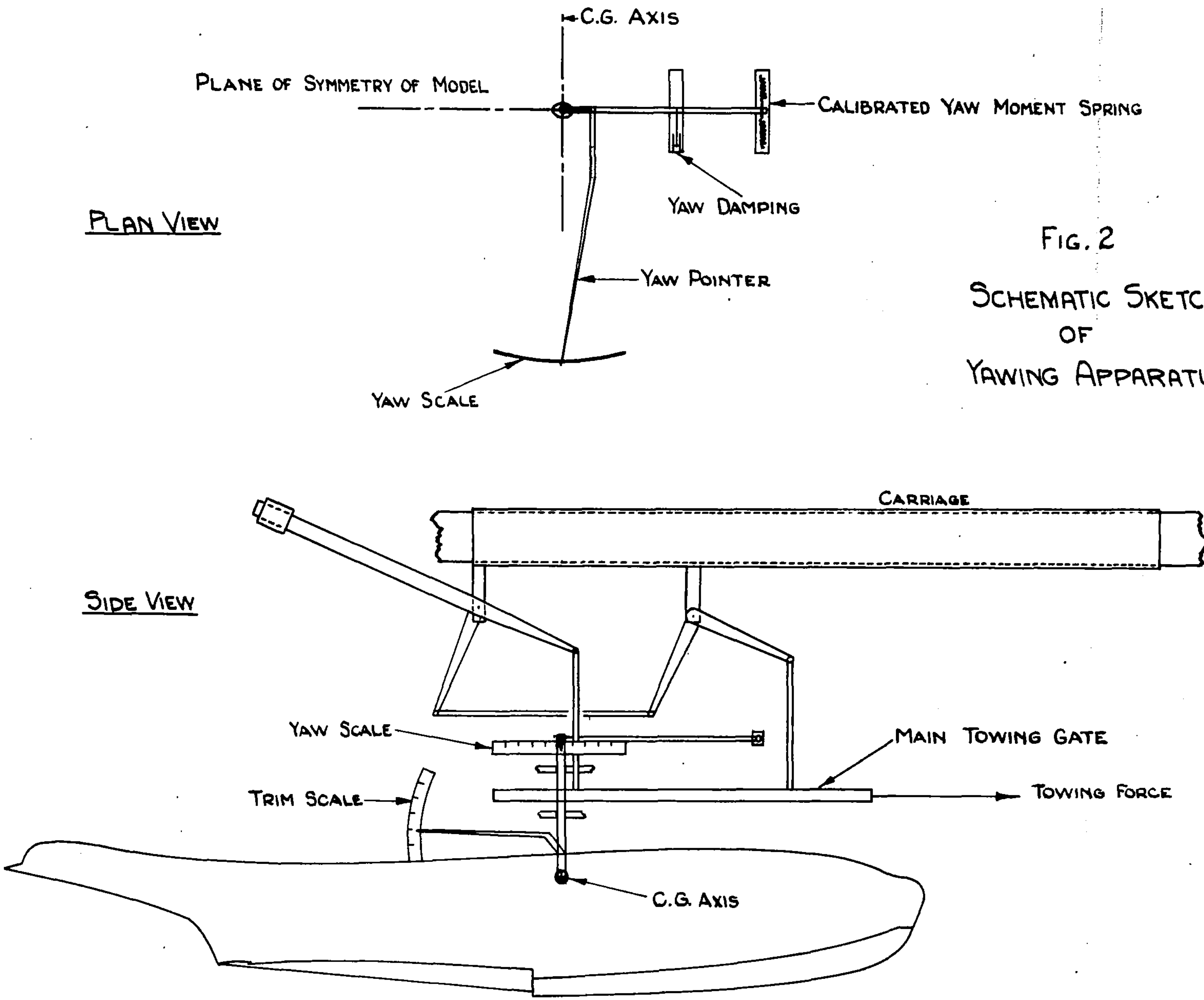

Fig. 2

Schematic Sketch of Yawing Apparatus

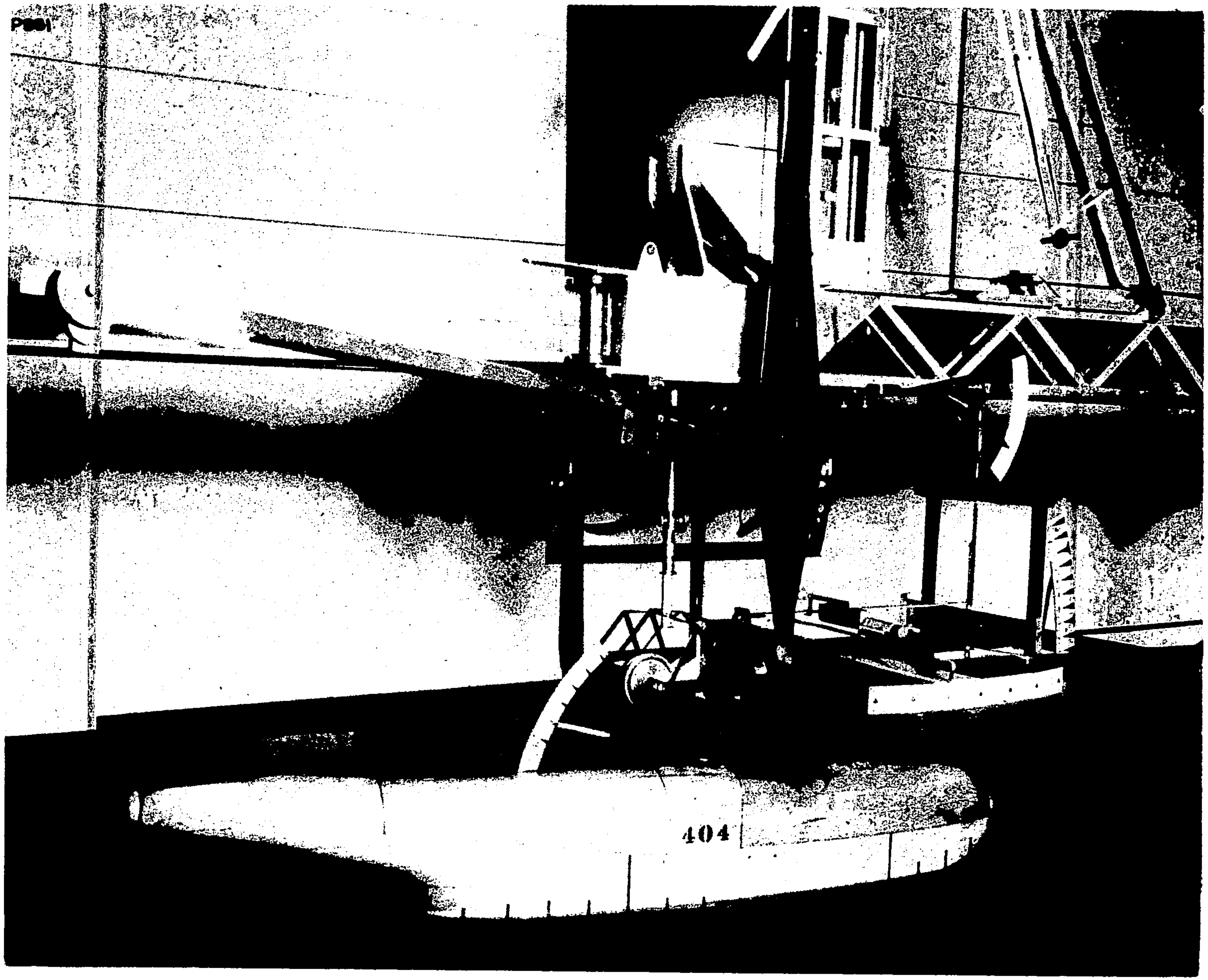

Figure 3.- Apparatus setup for yawing tests.

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(1 block = 10 divisions on 1/40" Engr. scale)

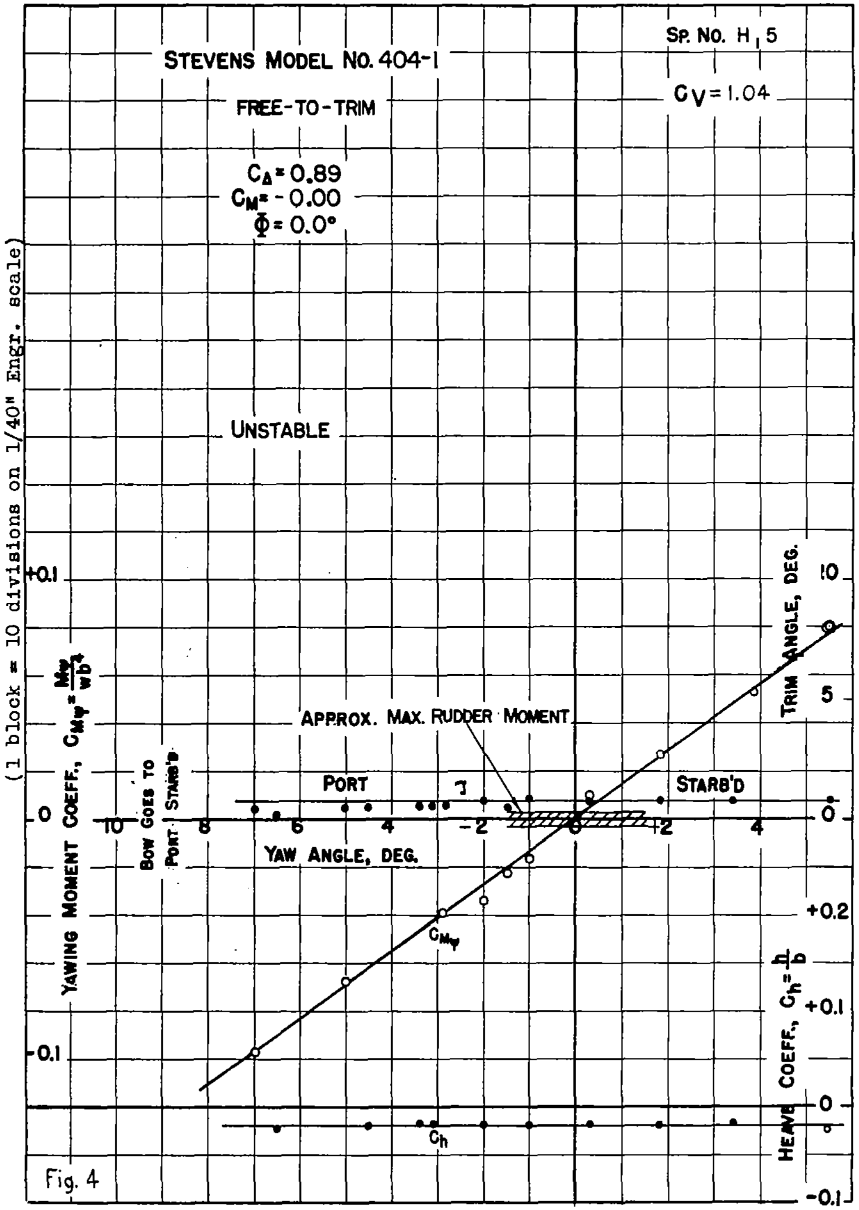

Fig. 4

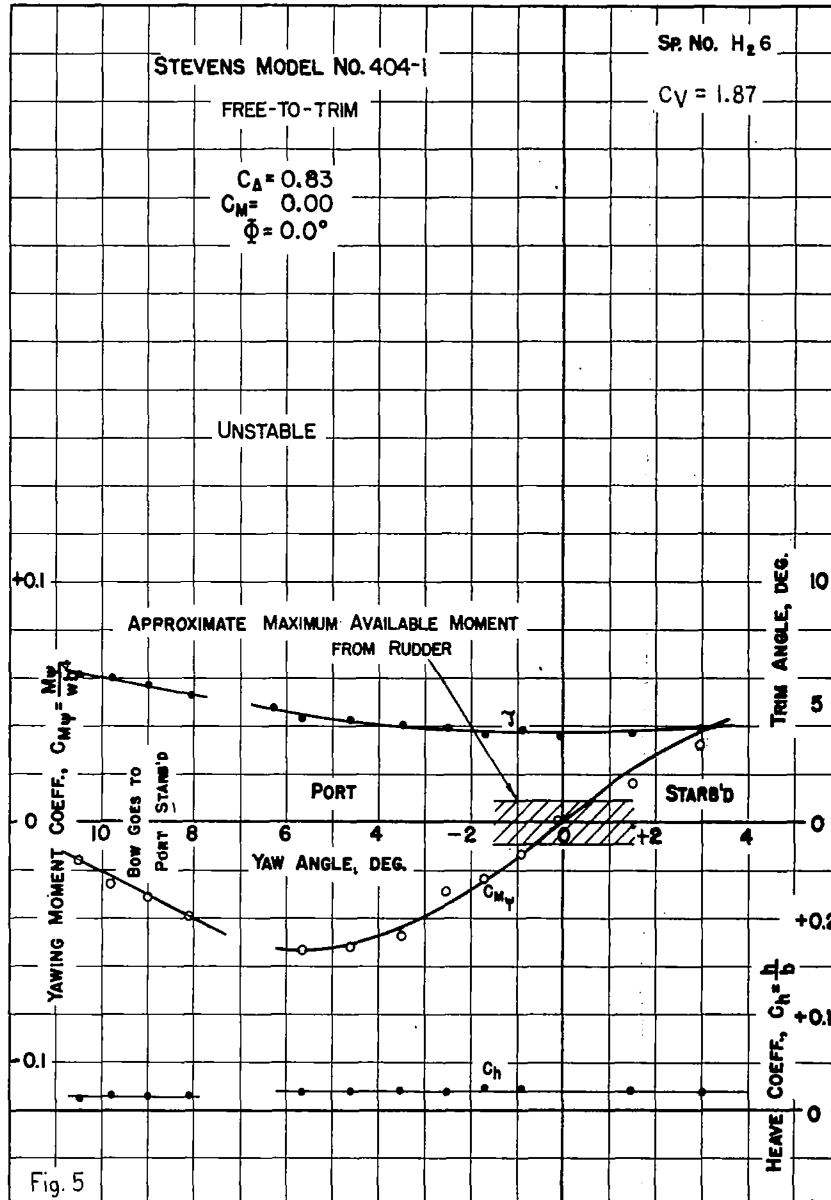

Fig. 5

Figs. 4,5

(1 block = 10/40")

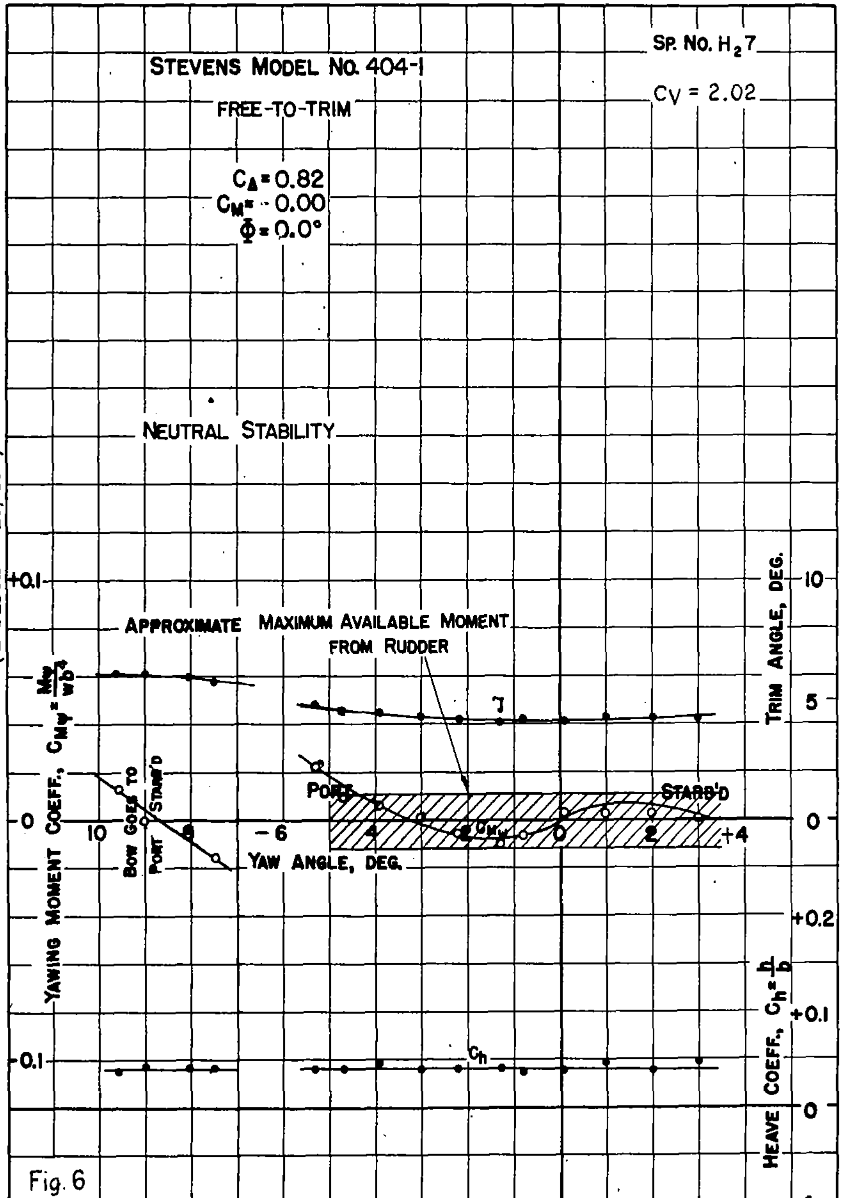

Fig. 6

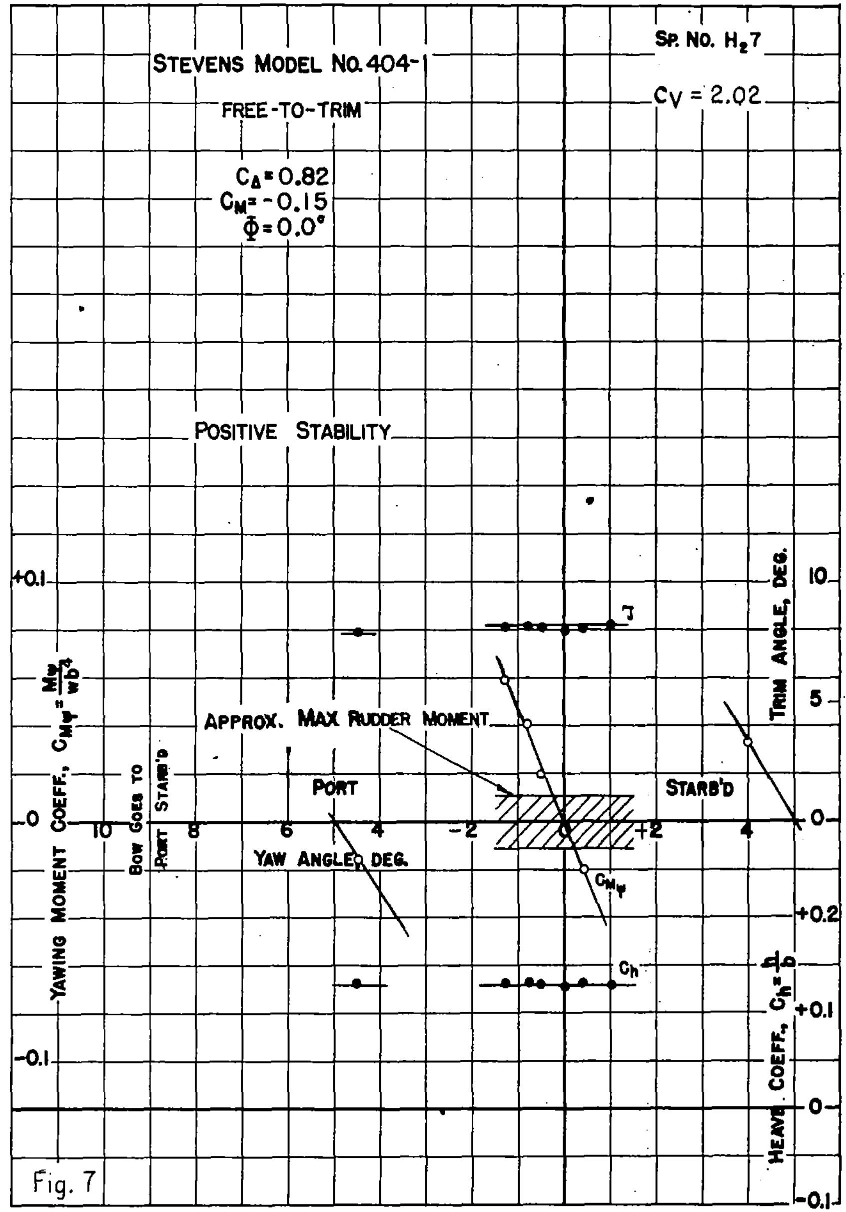

Fig. 7

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Figs. 6,7

(1 block = 10/40")

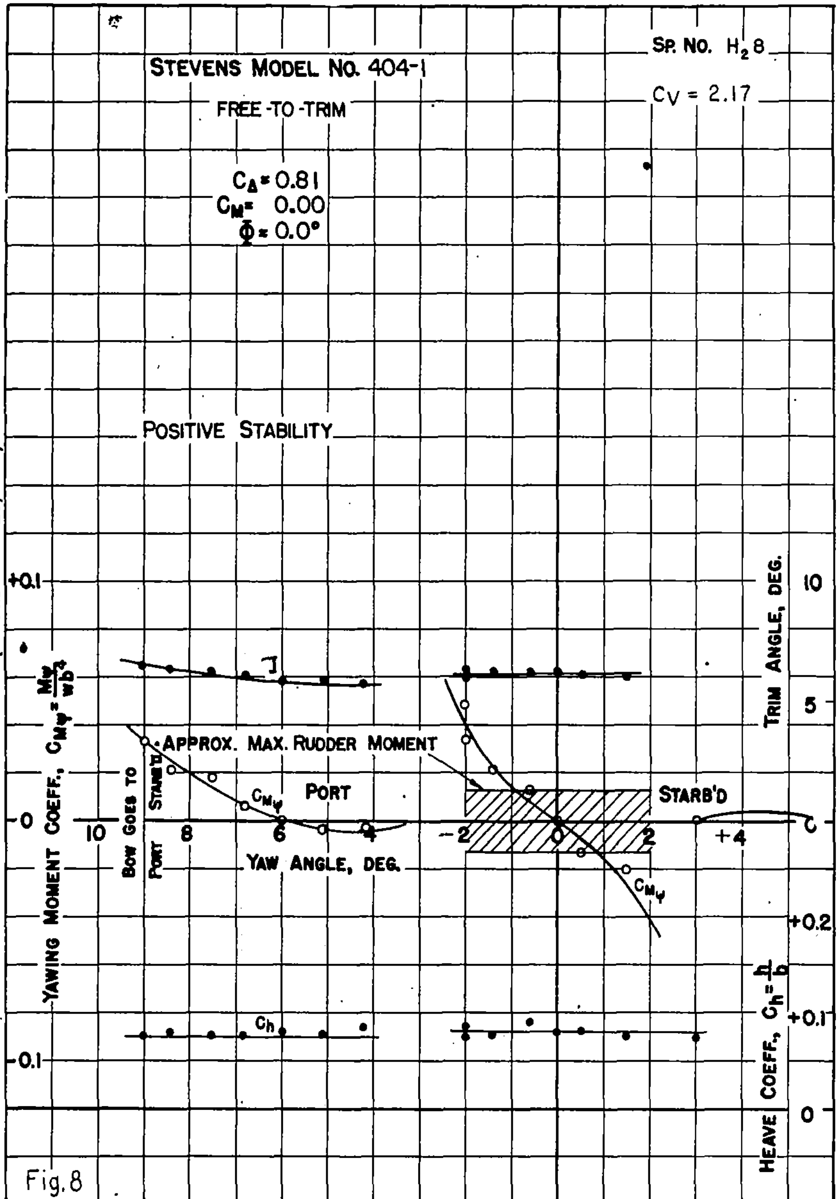

Fig. 8

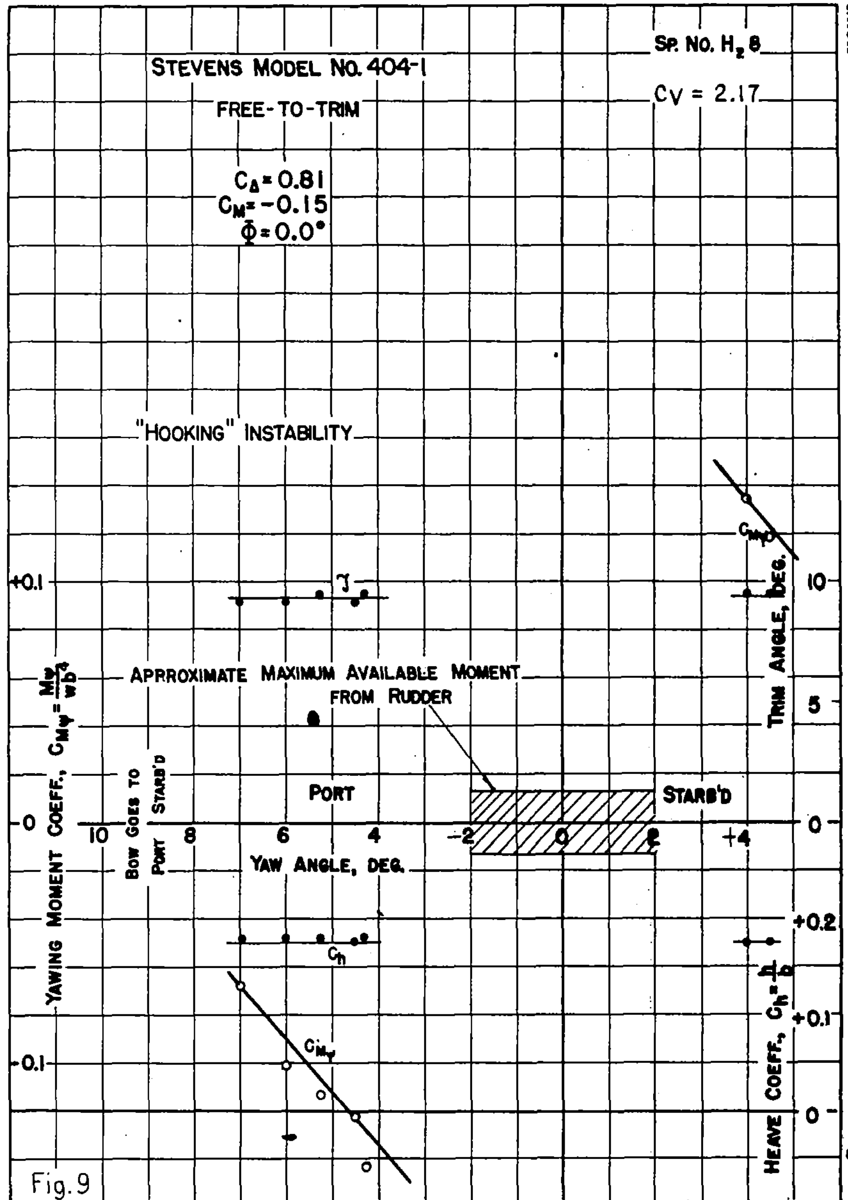

Fig. 9

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Figs. 8, 9

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(1 block = 10/40")

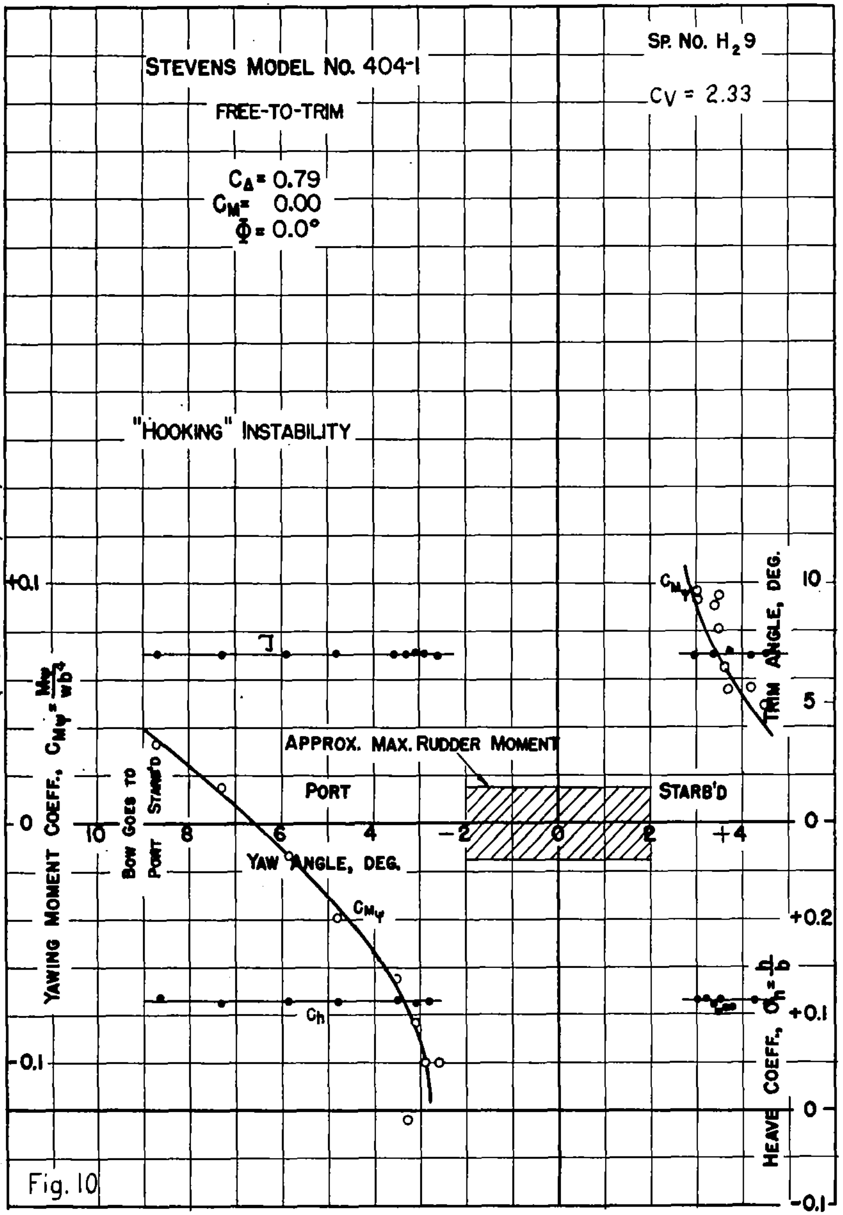

Fig. 10

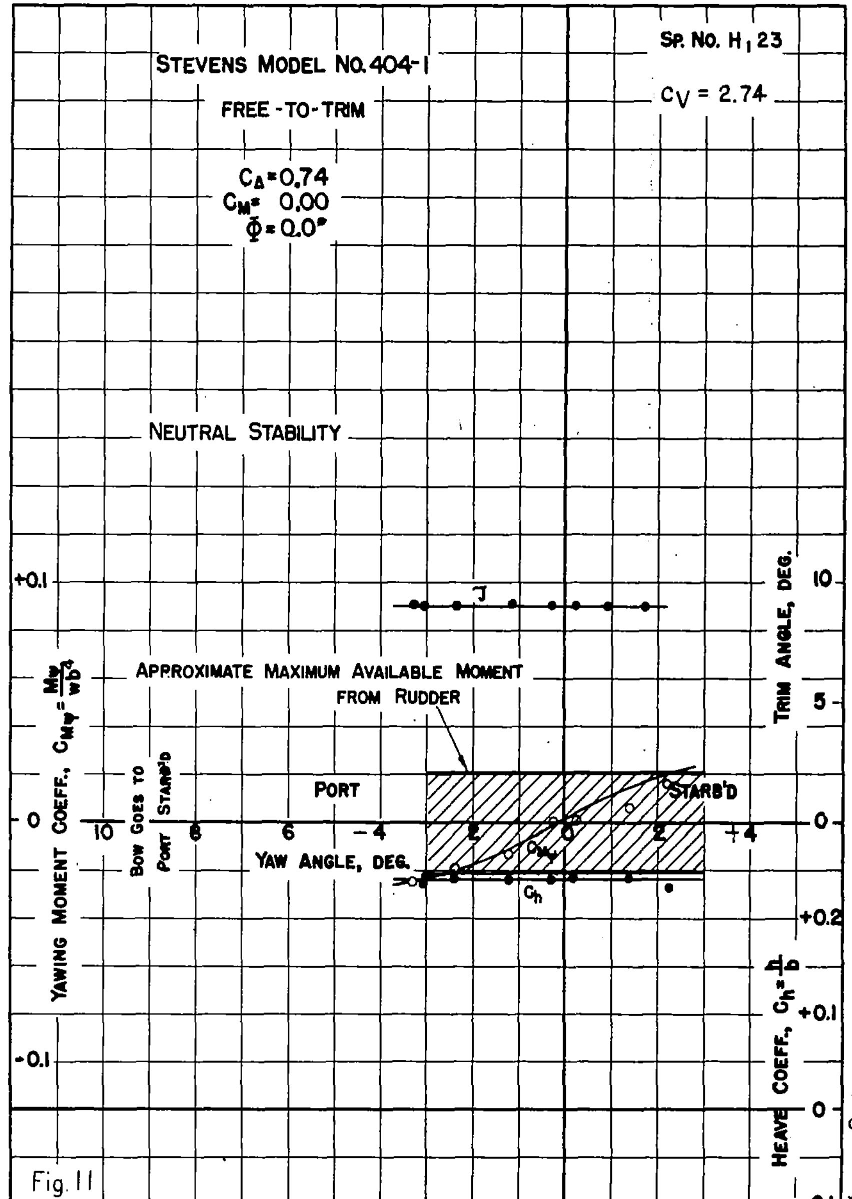

Fig. 11

Figs. 10, 11

(1 block = 10/40")

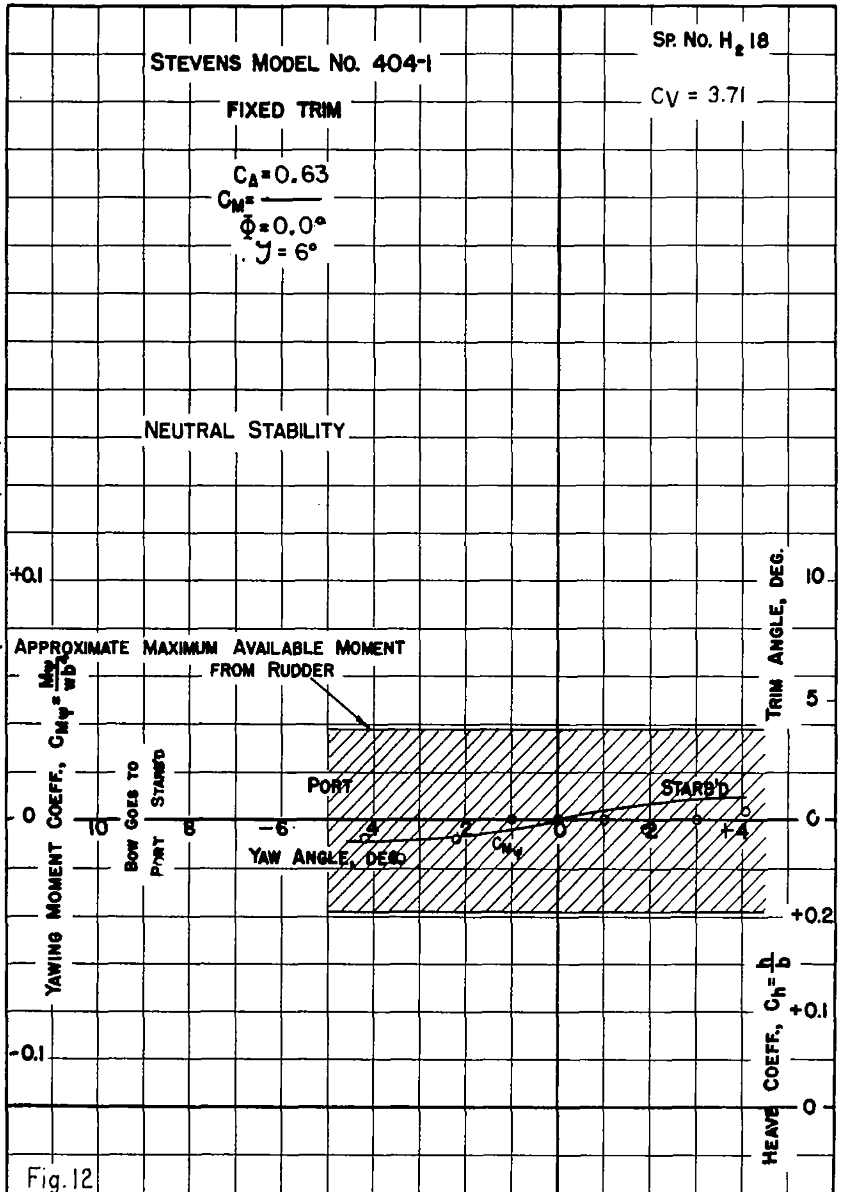

Fig. 12

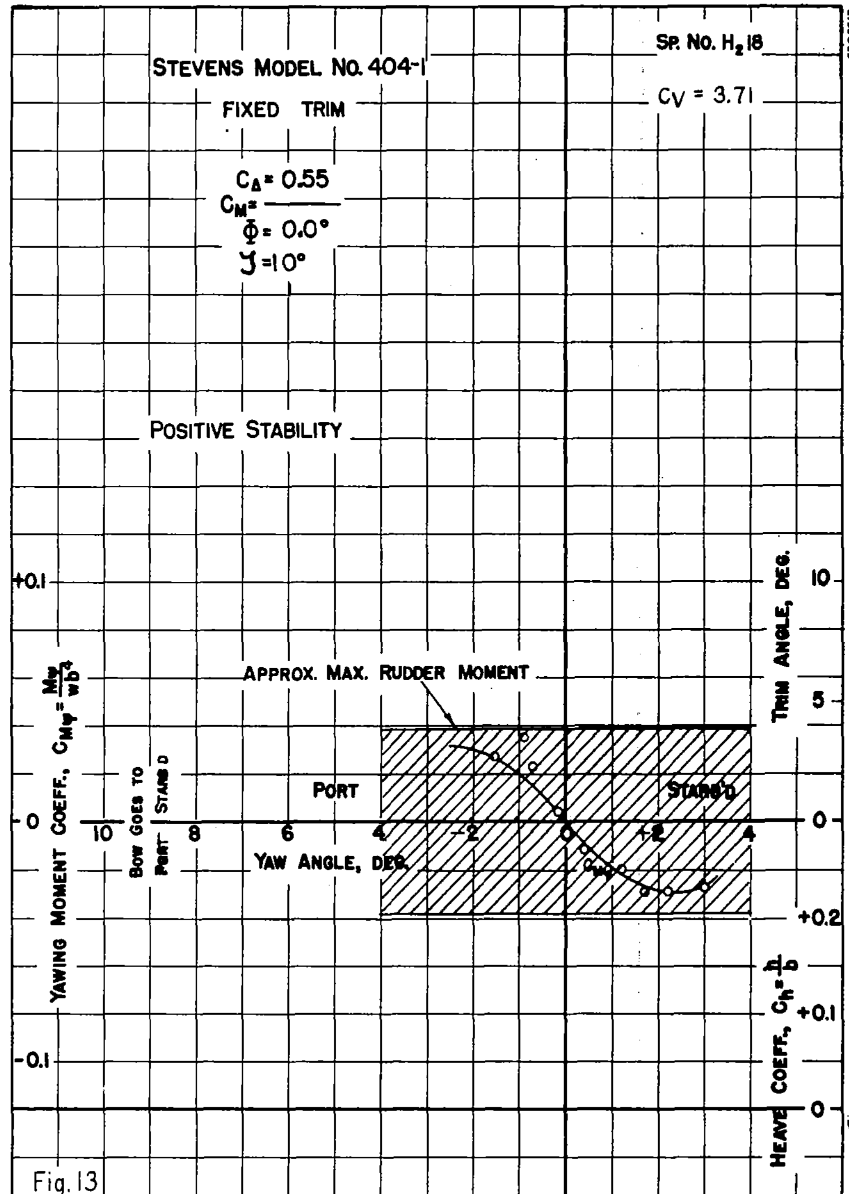

Fig. 13

(1 block = 10/40")

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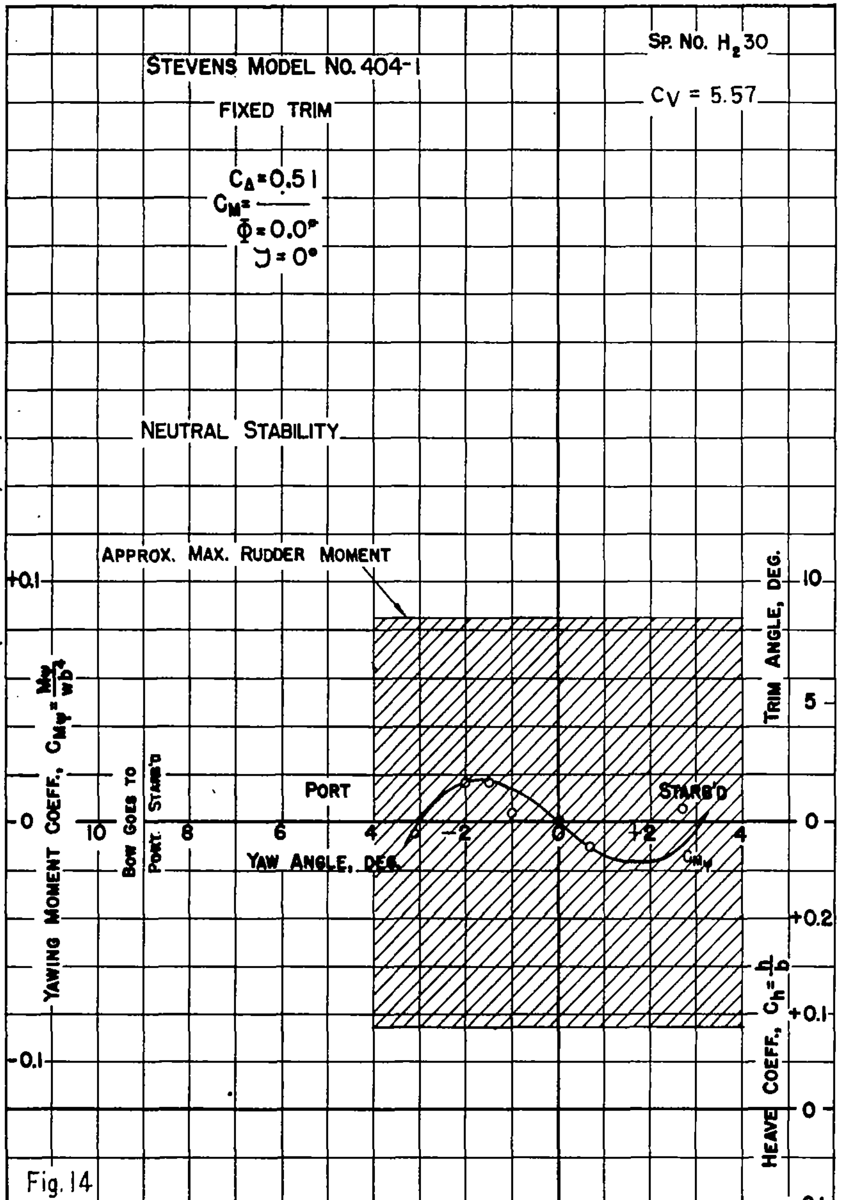

Fig. 14

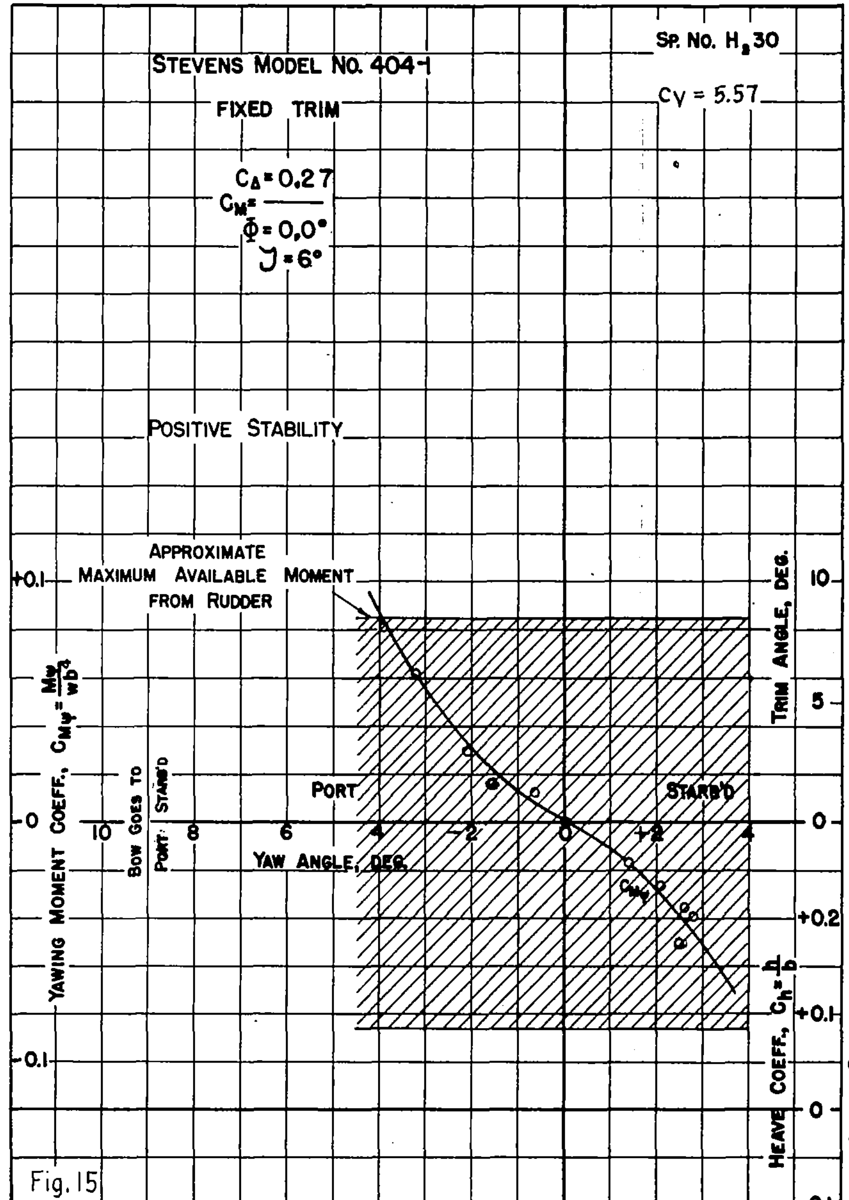

Fig. 15

Figs. 14, 15

(1 block = 10/40")

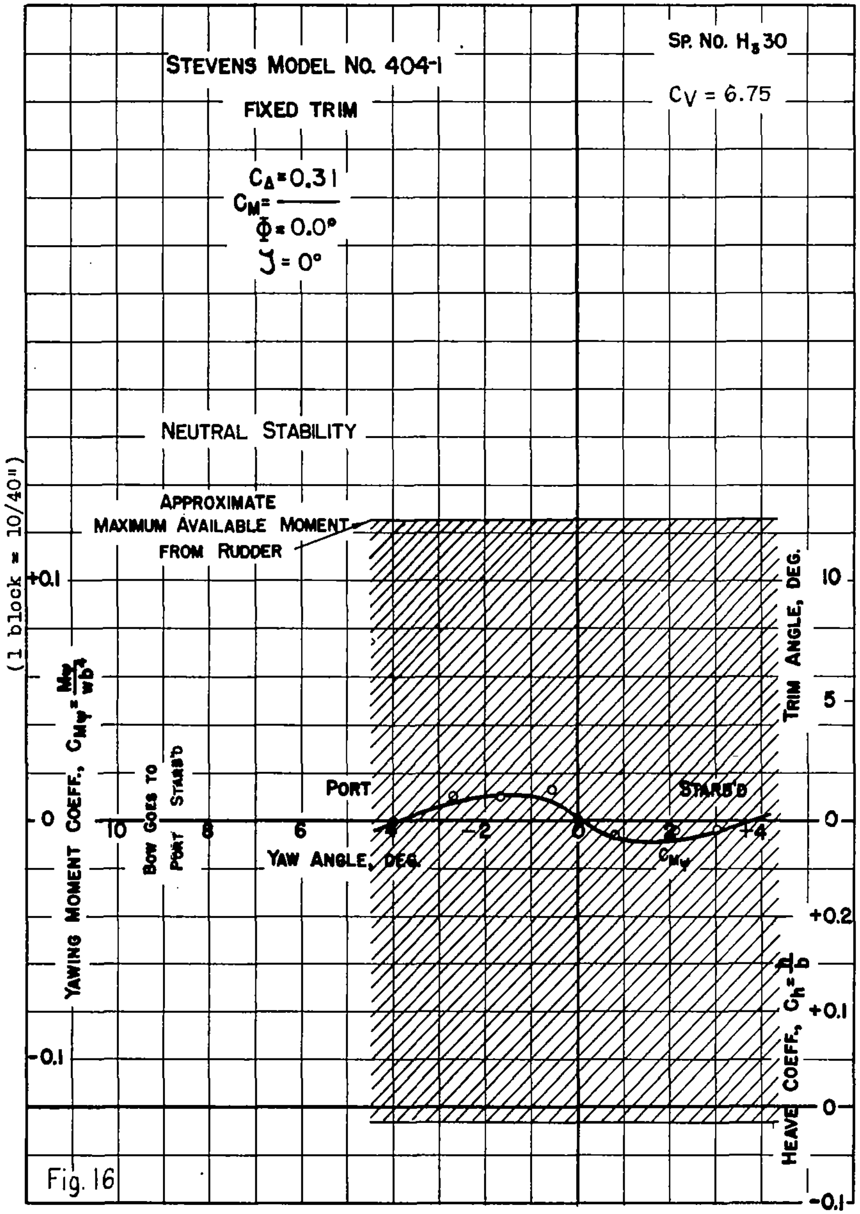

Fig. 16

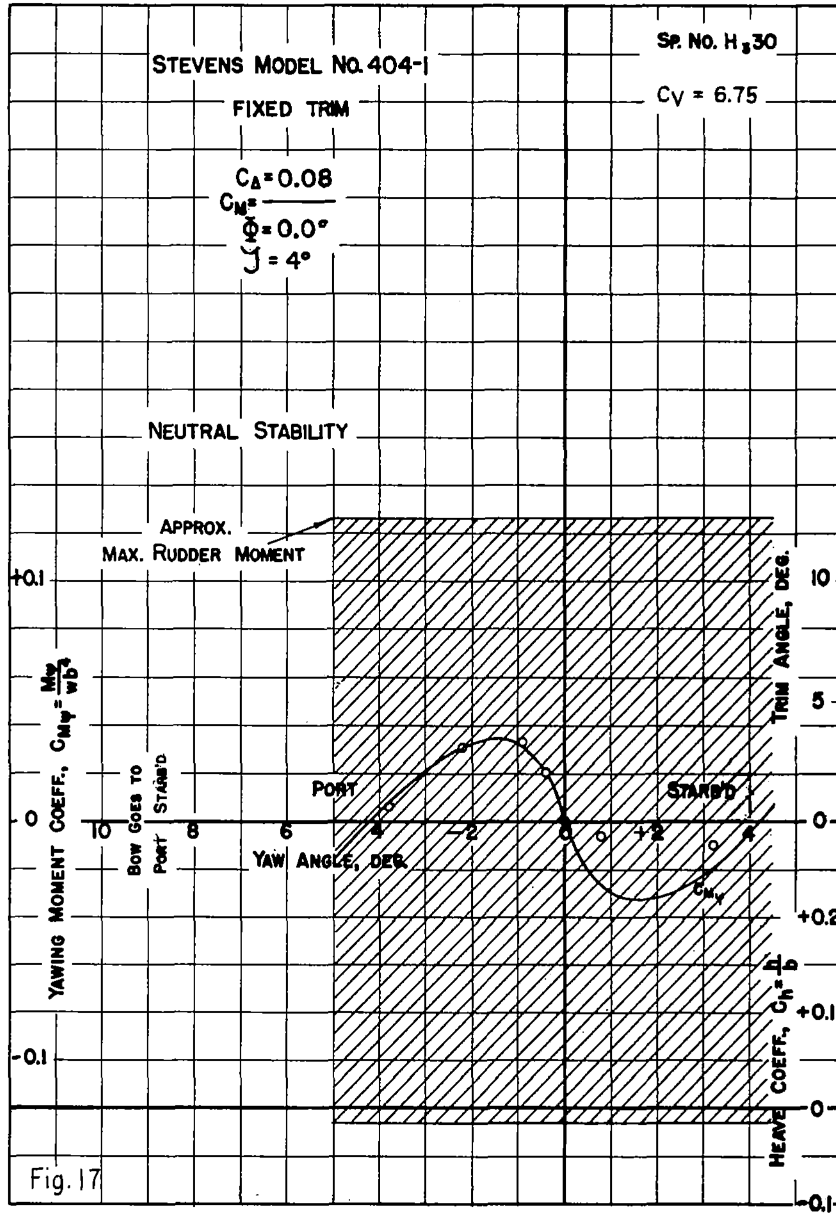

Fig. 17

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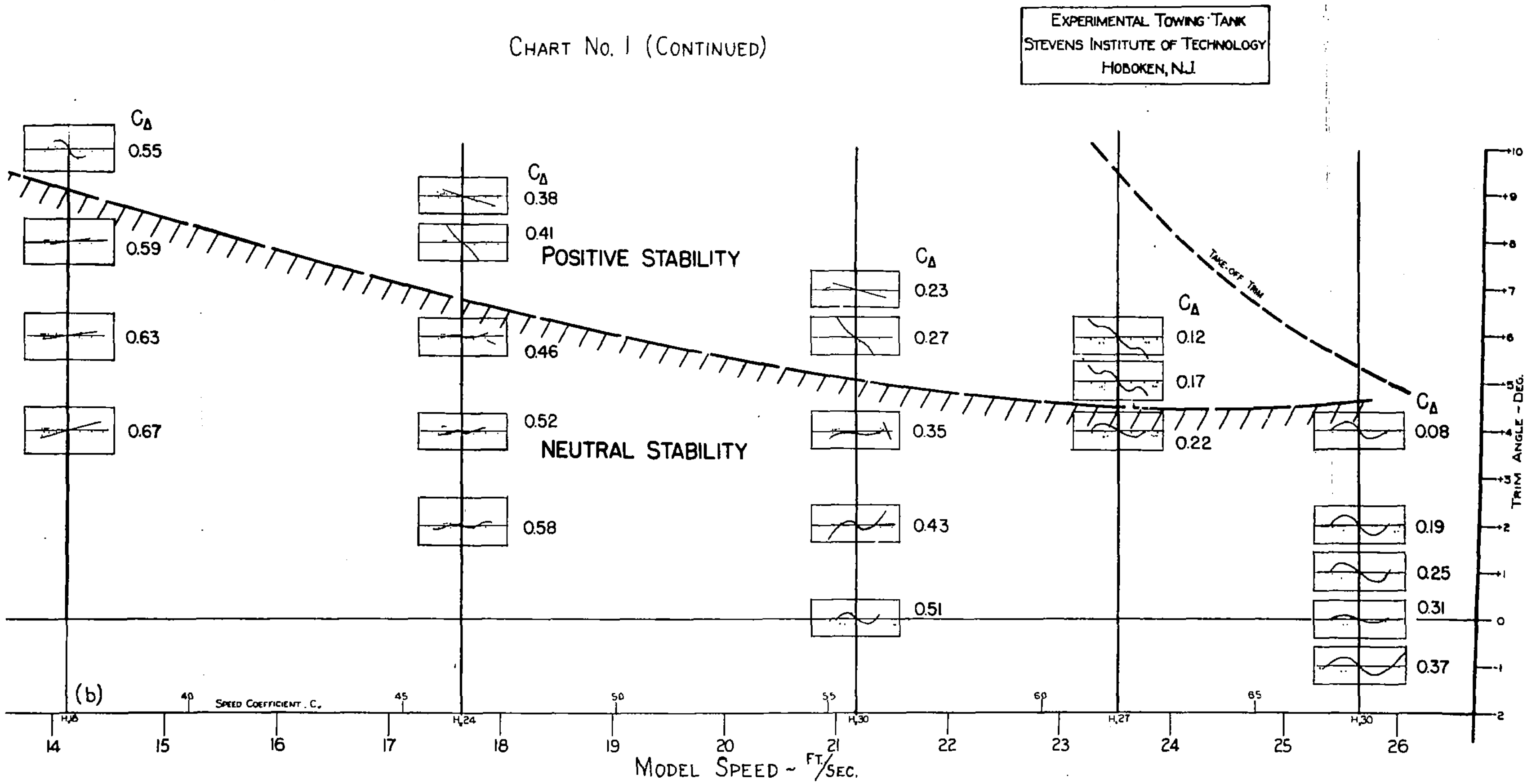
EXPERIMENTAL TOWING TANK
STEVENS INSTITUTE OF TECHNOLOGY
HOBOKEN, N.J.
CHART NO. 1 (CONTINUED)
POSITIVE STABILITY
NEUTRAL STABILITY
TAKE-OFF TRIM
C_Δ
0.55
0.59
0.63
0.67
0.38
0.41
0.46
0.52
0.58
0.23
0.27
0.35
0.43
0.51
0.12
0.17
0.22
0.08
0.19
0.25
0.31
0.37
(b)
SPEED COEFFICIENT, C_v
40
45
50
55
60
65
H,18
H,24
H,30
H,27
H,30
14
15
16
17
18
19
20
21
22
23
24
25
26
MODEL SPEED ~ FT./SEC.
TRIM ANGLE - DEG.
10
9
8
7
6
5
4
3
2
1
0
-1
-2

Fig. 18b